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An Investigation of the Effects of Glue on Light Transmission in Scintillating Fibers

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Abstract

Systematic studies of the effect of different types of glues and paints on the attenuation of light in scintillating fibers are described. Over a period of 9 months we observe no adverse effect from any of the glues studied. This conclusion holds true even when fibers are irradiated up to a dose of 1 MRad .

1. Introduction

Recent progress in scintillating fiber technology has made them a very attractive choice for high energy physics detectors. Fibers can be used for charged particle tracking^[1] , as preshower detectors^[2] and as an active medium and/or read-out element in calorimeters^{[3][4]} .

Construction of detectors frequently requires fibers to be glued to some other materials, or to themselves, for example to form ribbons. It has been shown that some glues have an adverse effect on the light guiding properties of plastic fibers^[6]. The effect of glue on plastic fibers may be even bigger when fibers are placed in high radiation dose environment. This is of a particular concern for detectors planned for the proposed new hadron colliders, where it is expected that the radiation doses over the lifetime of an experiment may reach tens of MRad, especially in the forward direction.

For this reason it may be necessary to avoid any contact of glues with fibers. Such a restriction may complicate the construction techniques, making some detectors very expensive, or even impossible to construct. It is therefore very

important to establish the effect of different glues on the scintillating fibers, in particular over long time periods and in high radiation fields.

2. Fibers and glues

We have studied a sample of polystyrene fibers, 1 mm diameter, with 30 μm PMMA cladding. Fibers were doped with Y7 waveshifter, shifting the emitted light to the region of 500 - 550 nm. They were produced by Kuraray^[6]. Since the effect of glue on the fiber will be concentrated at the outer cladding, it is expected that our results should be representative for a wide class of scintillating fibers with PMMA cladding.

We have studied several common types of glues which could be used in the construction of detectors, see Table 1.

The presence of glue around the cladding of a fiber will alter the boundary conditions for light reaching the cladding-air interface. PMMA has a refractive index $n=1.49$, whereas glues may have refractive indices higher, or lower than the cladding (Table 1). There are several components of light propagating along the fiber. They can be broadly classified as 'core' light (i.e. light propagating within the core, and reflecting off the cladding-core boundary) and 'cladding' light (i.e. light captured by total internal reflection at the cladding-air interface). One may therefore expect, that in all applications where the core light is dominant, glue should not affect the waveguide properties of fibers. Chemical effects are a potential worry in that the glue may cause significant damage to the cladding or even the core itself. These effects may be particularly important in a radiation field, as the products of radiolysis of the glue may prove very active and/or mobile.

It is well known that radiation damage to plastic scintillators and the subsequent annealing depends on the presence of oxygen in a surrounding atmosphere^[7]. For this reason glues which exhibit high permeability for oxygen, like RTV, may be of a particular importance.

Table 1		
Glue	Refractive index	Manufactured by
Epon 828	1.573	Shell Chemical Company ^(a)
RTV 615	1.423	General Electric ⁽⁹⁾
Translucent	1.50	3M ⁽¹⁰⁾
Bicron 600	1.56	Bicron Corp ⁽¹¹⁾
Epotek 302	1.566	Epoxy Technology ⁽¹²⁾

3. Experimental Setup and Measurements.

The experimental setup (see Fig. 1) consisted of a 2 m long brass block with 2 mm deep, V-shaped groove on its top. The block and the interior of the groove were painted black. A mercury lamp (Oriel 6035) was mounted in an aluminium holder with 1 mm wide, 5 mm long slit. The holder was free to move along the rail, some 1 cm above the V-groove, with the slit perpendicular to the groove. The position of the UV lamp along the groove was controlled by an IBM PC. Both ends of the fiber were read out with PIN photodiodes (Hamamatsu S1723-06) or photomultipliers. The photodiode current was measured using picoammeters (Keithley 485) and read out through IEEE488 bus into the IBM PC.

The fibers were typically 2.1 m long. Both ends of the fiber were cut perpendicular to the fiber and polished using # 2000 sanding paper. The fibers were laid in the V-groove, and photodiodes were adjusted to touch the end of fibers. No optical grease was used.

The mercury lamp was moved typically in 25 cm steps along the fiber, and the light yield was measured at 8 points along the fiber. The attenuation length was calculated from the observed dependence of the photodiode current on the position of the UV lamp. The complete measurement took some 2 minutes, the UV lamp was found to be stable within such an interval to better than 1%.

The current measured at different positions of the lamp may depend on several factors which are beyond our control such as the thickness of the cladding, the distance between the fiber and the UV lamp etc... To eliminate these factors we have used the ratio of the currents of photodiodes at both ends of the fiber; to first order this cancels any variation of the light output at the production point.

Some residual effects may be due to the different spatial distribution of the emitted light within the fiber. The advantages of this technique are illustrated in Fig. 2.

Attenuation of light in the fibers is a rather complicated process, and in general cannot be described by a single exponential. The deviations from a single exponential attenuation curve occur at short distances, mostly due to the contribution of the cladding light, which has much shorter attenuation length. These deviations can be greatly reduced by painting a small section, at the end of the fiber with black paint^[33] as shown in Fig. 3 . At the same time the measured attenuation length even in the central part of the fiber increases by about 25%. This indicates this existence of a light component with relatively long attenuation length, of the order of 2 m , which is sensitive to the state of outer boundary of the cladding. This may be an important fact for all applications where uniformity of fibers is required.

To reduce the influence of the geometrical factors and of the residual cladding light, only measurements taken at a distance greater than 30 cm from the photodiodes were used for the determination of the attenuation length. The attenuation length of the fibers was obtained by fitting the ratio of responses of the two photodiodes to the formula

$$R(x) = A \exp(-2x/\lambda)$$

where

$R(x)$ is the ratio of currents of photodiodes

x is the distance of the UV lamp from the photodiode

λ is the attenuation length

A is the overall normalization factor

This formula is expected to provide an adequate description of the ratio of measured currents in the range, where the attenuation can be approximated by a single exponential.

4. The effect of glue on the attenuation length

Samples of the 2.1 meter long fibers were divided into batches of 8 fibers. Both ends of the fibers were painted with a black paint. After the measurement of the attenuation length of all fibers, each batch was covered with a specific glue. Free spaces 3 cm long were left glue-free at 25 cm intervals to enable excitation of fibers with the UV lamp. Fig. 4 shows the typical effect of the glue on the attenuation length of fibers. For a fiber covered with glue the actual light yield varied wildly with the position of the lamp, but these variations cancel out in the ratio. It is evident that the presence of glue does not cause any degradation of the attenuation length of the fiber.

The attenuation length of the fibers was measured using the procedure described previously. Fibers with and without glue were excited with the UV lamp at 25 cm intervals and the attenuation length was determined fitting 6 measurements in the central part of the fiber. Values of the attenuation length within any particular batch of fibers had a scatter with a typical RMS of 5%. As a result, the average value of the attenuation length for a group is known to 1-2%. To check the reproducibility of the results we have re-measured some of the groups of fibers, and we have found that the results are reproducible at the level of 1%.

Measurements of the attenuation lengths were carried out periodically, over a period of 9 months. The results are shown Fig. 5 which shows the attenuation length as a function of time. We observe that the glues used in our studies do not affect the attenuation length of fibers in any major way. The biggest effect is the 7% drop of the attenuation length for Bicron 600 glue. In addition, we see no indication of any long term effects over a period of 9 months.

5. Effect of glue in the radiation field.

Samples of fibers were prepared in a similar manner to that described above. For technical reasons, related to the irradiation procedure, the fibers were 130 cm long. Both ends of the fibers were painted with black paint and, after the measurement of the initial attenuation length, the fibers were covered with glue. Nine glue-free regions, spaced by 13 cm were used to excite fibers with the UV lamp. In addition to fibers covered with glue, we prepared two control samples: one was covered over its whole length with the black paint instead of glue, the other was left in its original state with only the ends painted black. The fibers were irradiated using the 1 MeV electron beam at the Florida State University in Tallahassee. For the irradiation, the fibers were coiled on a disk with radius of 36 cm. Rotation of the disk in the electron beam assured uniform radiation

dose over the entire length of the fibers. The radiation dose was measured using radiochromic films^[14] placed in front of the fibers.

Fibers were irradiated in air to a dose of 1 MRad with a dose-rate of 4 MRad/hour. After the irradiation all the fibers were kept in room temperature in air. The attenuation length of fibers was measured periodically using our standard procedure. The attenuation length was determined from the exponential fit to the ratio of the photodiodes output as a function of the position of the UV lamp over the central 70 cm of the fiber. The fact that these fibers were shorter, and hence the increased importance of end effects, is responsible for the lower attenuation length values than those of Fig. 5. Results of the measurement over 4 months after the irradiation are shown in Fig. 6. We observe a decrease of the attenuation length after the irradiation and a recovery with time. The annealing time scale is of the order of two weeks, and the resulting attenuation is around 120 cm. We did not observe any significant degradation of the attenuation length which could be attributed to the glue or the black paint.

6. Conclusion

We have performed systematic studies of the possible effect of various types of glues and of black paint on the attenuation of light in scintillating fibers. We have found the the presence of glue at the outer surface of cladding does not affect the attenuation length. For the class of glues used in these studies we do not observe an adverse effect of the glue over the period of 300 days. We have irradiated samples of fibers up to a dose of 1 MRad using low energy electron beam. We have observed the familiar pattern of the drop of the attenuation length and subsequent recovery. As before, we did not observe any significant degradation of the light guide properties of the fibers due to the presence of glue.

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FIGURE CAPTIONS

- 1) Experimental setup for the measurement of the attenuation length.
- 2) a) Dependence of the current measured in photodiodes at both ends of the fiber as a function of the position of the UV lamp. It is clear that local fluctuations, at the level of 10%, are due to the variation of the light yield, as both measurements are strongly correlated.
b) Ratio of currents of the photodiodes as a function of the UV lamp position.
- 3) Ratio of currents in photodiodes at both ends of the fiber as a function of the position of the UV lamp for fiber with and without black paint on both ends. Straight lines represent an exponential fit to a central section of the fiber.
- 4) Ratio of currents in photodiodes as a function of a position of the UV lamp for before and after application of the glue (translucent, in this case). In both cases, the ends of the fiber were painted with black paint. Crosses indicate position of the photodiodes.
- 5) Attenuation length of fibers covered with glue as a function of time. Each point represents the average of the batch of fibers. Points at 'negative' time represent the attenuation length for this batch of fibers before application of glue.
- 6) Attenuation length of fibers as a function of time after the irradiation. Data points represent the average value of batches of fibers. Points at 'negative' time represent values before the irradiation.

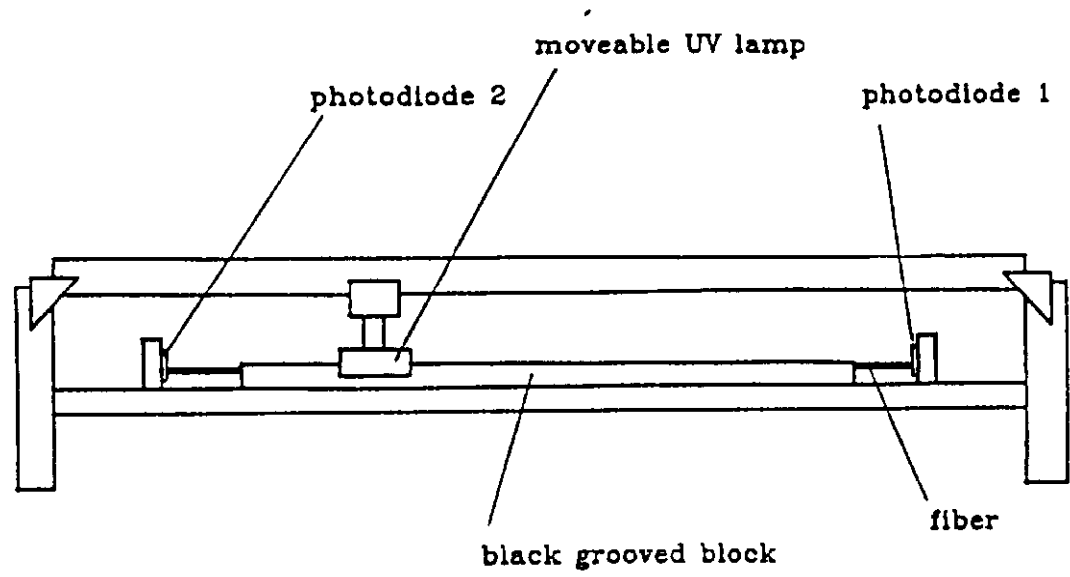


Fig. 1

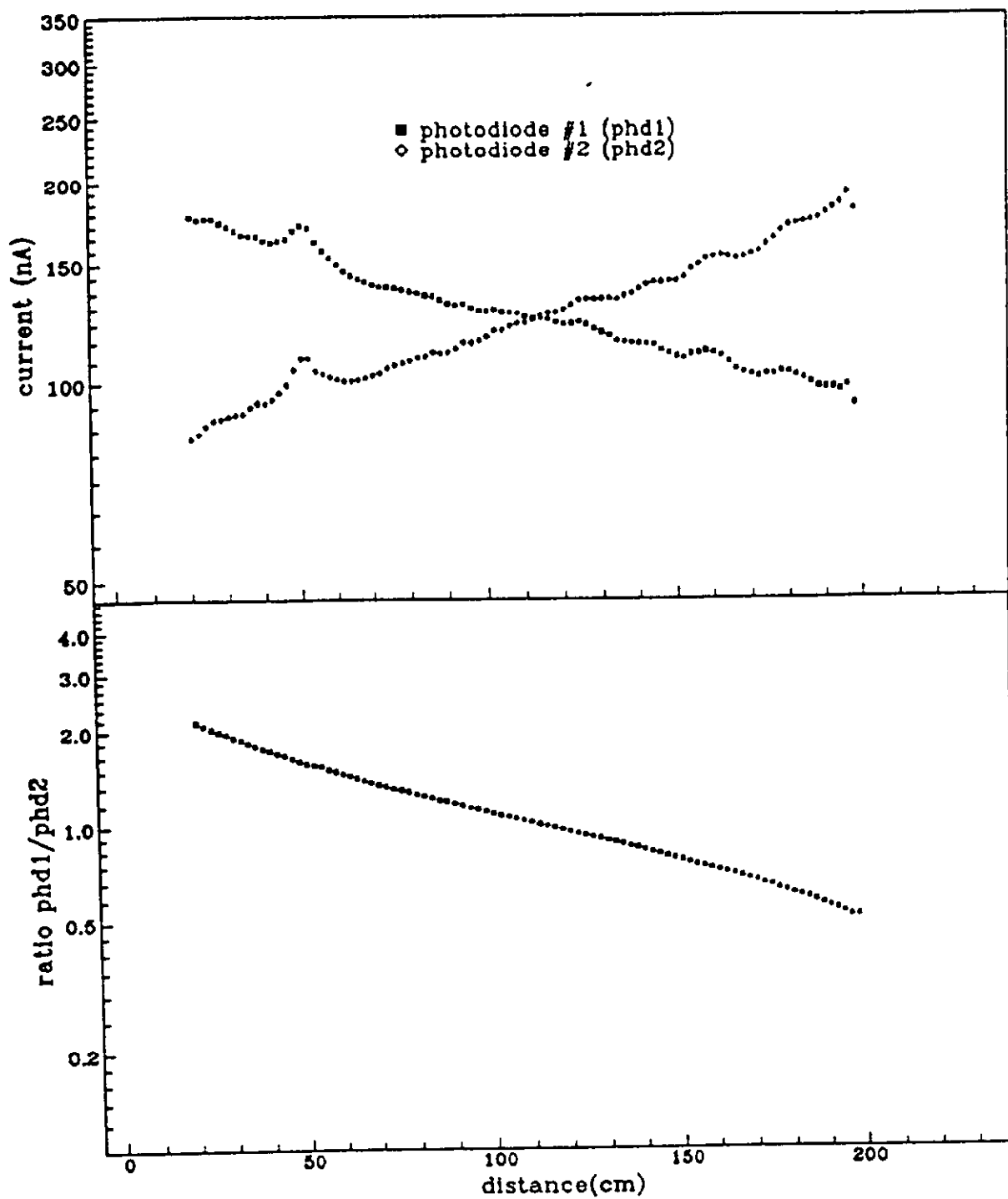


Fig. 2

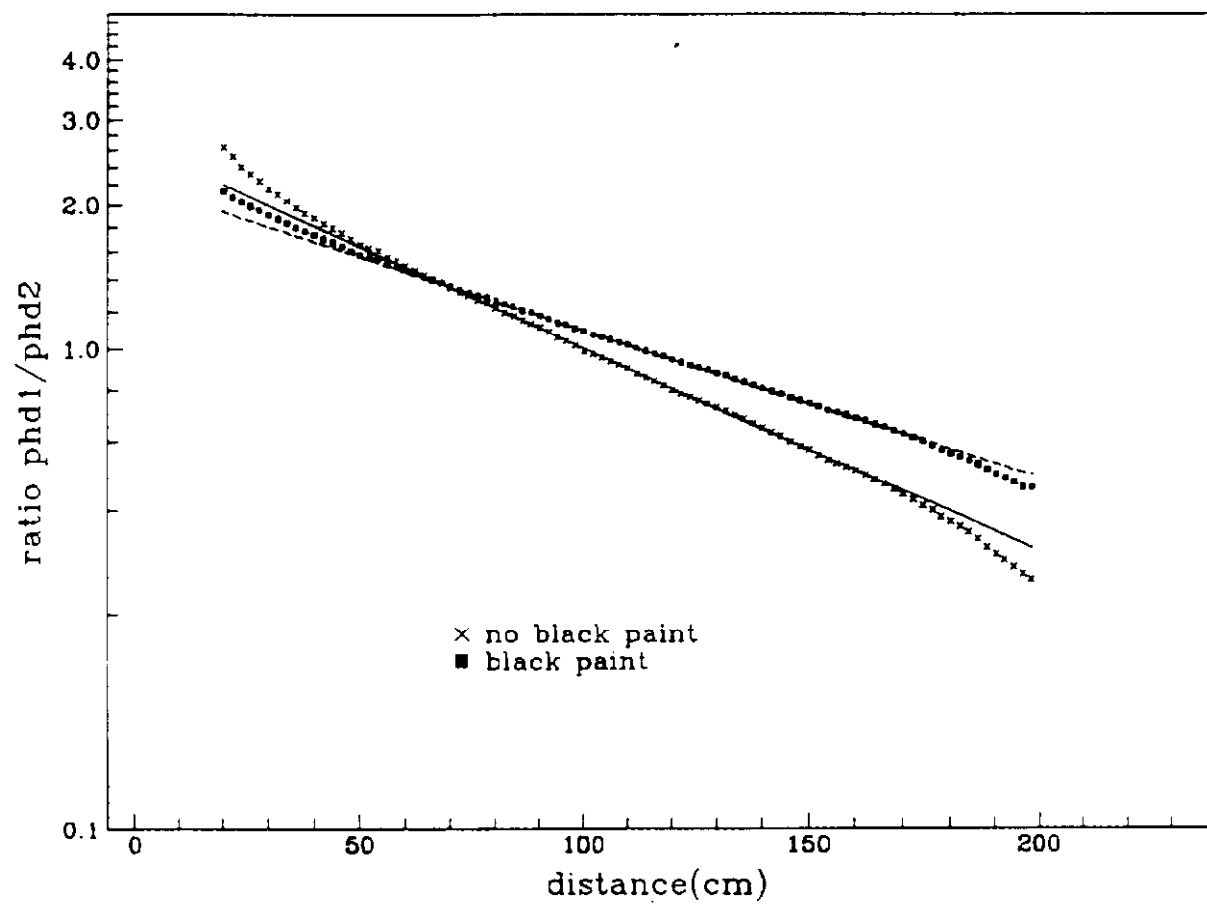


Fig. 3

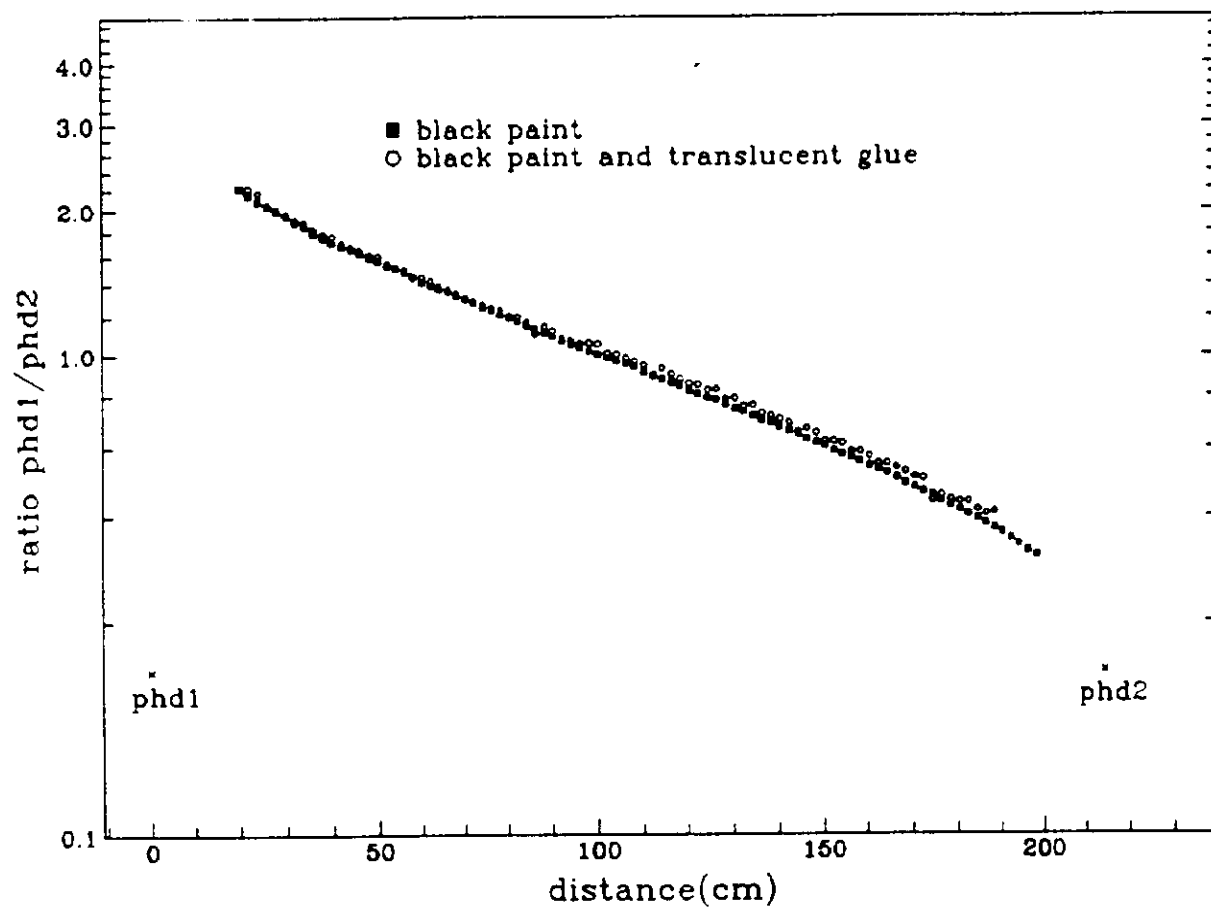


Fig. 4

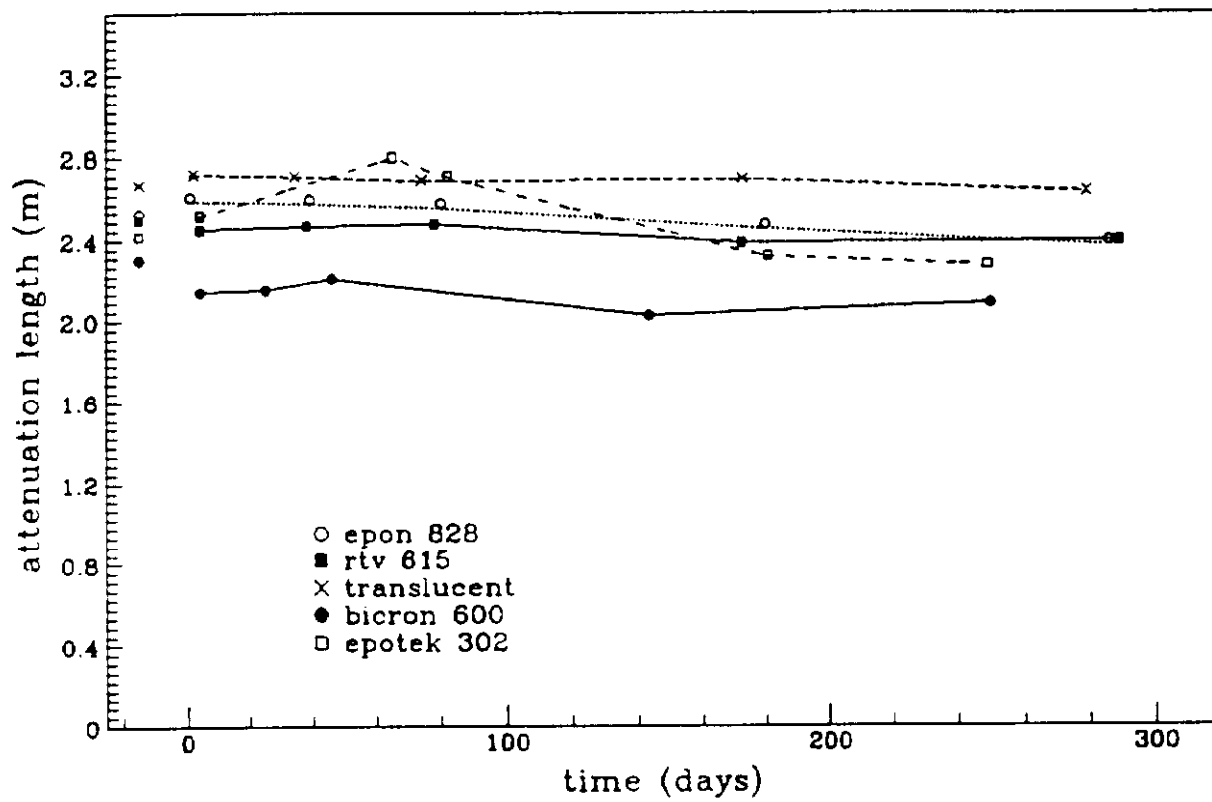


Fig. 5

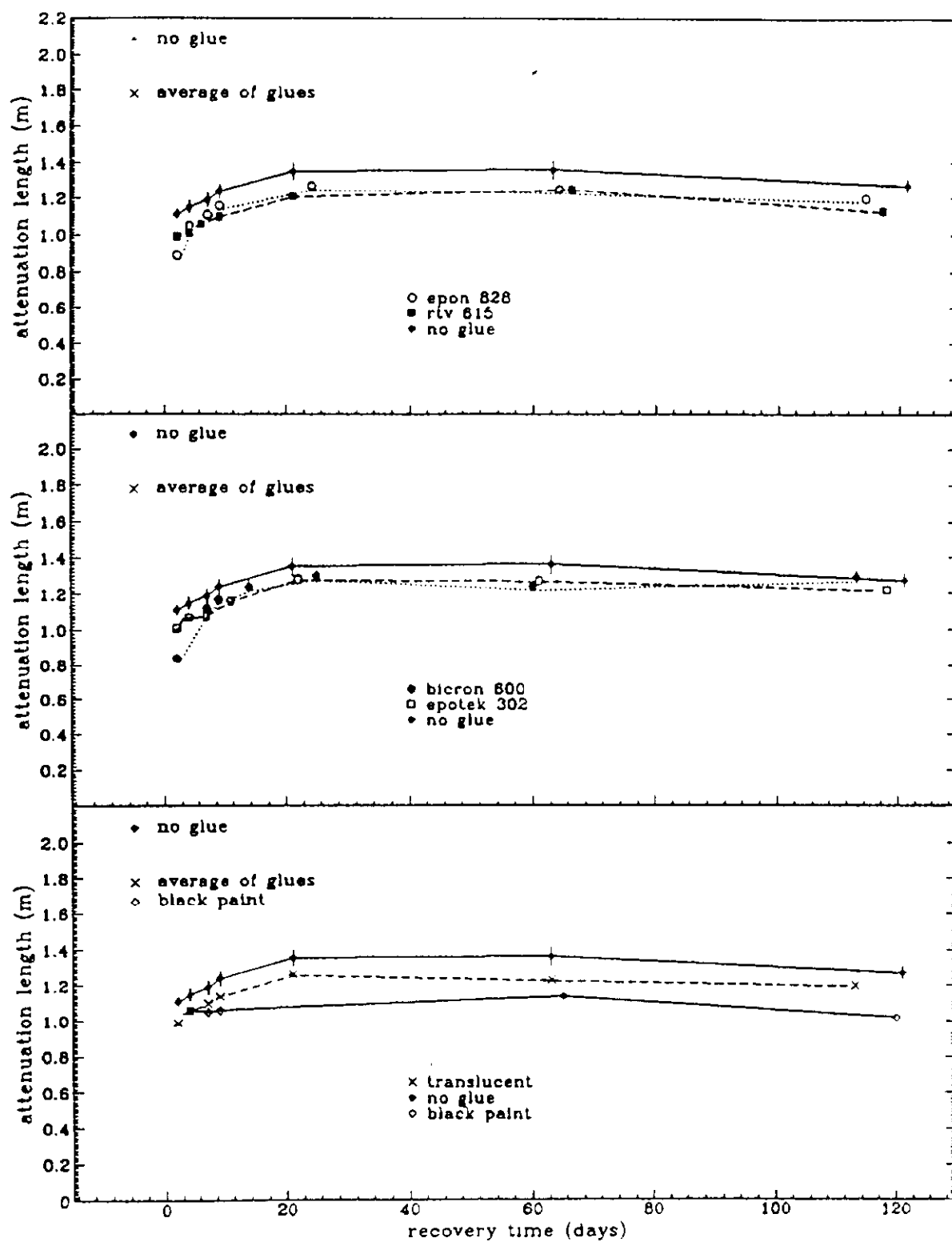


Fig. 6